RAM AIR TURBINE ENHANCEMENT FOR AUXILIARY POWER UNIT REPLACEMENT

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Dedicated to my beloved mother, Fatima Ali and my father Mohammad Saad. To my supervisor, Dr. Sofian Bin Mohd, Dr. Mohd Fadhli Bin Zulkafli and friends for all of their love, endless support and encouragement

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ABSTRACT

Fossil fuels are currently the primary energy source of aircraft and cause harm to the environment. This study highlights the use of clean energy instead of fossil fuels in aircraft. This work aimed to study the possibility of dispensing auxiliary power unit (APU) in aircraft powered by fossil fuels to reduce air pollution and the total fuel cost used in aircraft. Multiple drawbacks were recorded from APU usage, such as relatively high operating cost, undesired emissions, and noise. In this project, ram air turbine (RAT), which are already equipped in aircraft, was enhanced to generate the amount of energy produced by APU. Two approaches were adopted in order to achieve the goal. The number of RAT units in the aircraft body were increased, and the classical RAT design was improved by adding a counter-rotating system (counter-rotating RAT - CRRAT). The design of RAT blades was based on blade element momentum (BEM) theory. The performance of RAT and CRRAT was analyzed using FLUENT software. The adopted numerical scheme was the Navier–Stokes equation with k–ω (SST) turbulence modeling. In order to numerically simulate the actual turbine operation, the dynamic mesh and user define function (UDF) were used to revolve the rotor turbine via wind. This study was performed in two stages. The first stage was conducted to evaluate the power produced from a single-rotor RAT. Three RATs were required to fulfill the APU power output, and the best location for RAT placement was under the wings and the belly of the aircraft. The second stage aimed to evaluate the amount of power generated from CRRAT and select the optimum axial distance of CRRAT. Results indicated that the optimum axial distance was 0.087 of rotor diameter, and the efficiency increased to 81.63% compared to that of the single-rotor RAT (conventional RAT). The power output of CRRAT placed at the optimum axial distance was assessed. The power produced by CRRAT was in positive agreement with simulation results. Thus, CRRAT could be used for all aircraft equipped with traditional RAT.

ABSTRAK

Bahan api fosil kini merupakan sumber tenaga utama pesawat dan menyebabkan kerosakan kepada alam sekitar. Kajian ini menyerlahkan penggunaan tenaga bersih dan bukannya bahan api fosil dalam pesawat. Kerja ini bertujuan untuk mengkaji kemungkinan pengeluaran auxiliary power unit (APU) di dalam pesawat yang dikuasai oleh bahan api fosil bagi mengurangkan pencemaran udara dan jumlah biaya bahan bakar yang digunakan oleh pesawat. Kegagalan berganda telah direkod daripada penggunaan APU, seperti kos operasi yang agak tinggi, pelepasan yang tidak diingini, dan bunyi bising. Didalam projek ini, ram air turbine (RAT) telah dilengkapi dengan pesawat, untuk mempertingkatkan dan menghasilkan jumlah tenaga yang sama dihasilkan oleh APU. Dua tindakan telah diambil untuk mencapai matlamat ini. Bilangan unit RAT di dalam pesawat telah meningkat, dan reka bentuk RAT klasik telah diperbaiki dengan tambahan sistem counter-rotating (counter-rotating RAT - CRRAT). Reka bentuk bilah RAT berdasarkan pada momentum elemen bilah (BEM). Prestasi RAT dan CRRAT dianalisis menggunakan kaedah program FLUENT. Skema berangka yang digunakan adalah persamaan Navier-Stokes dengan pemodelan turbulensi k-ω (SST). Untuk mensimulasikan operasi turbin sebenar secara berangka, fungsi dinamik dan fungsi didefinisikan pengguna (UDF) digunakan untuk memutarkan turbin rotor melalui angin. Kajian ini dilakukan didalam dua peringkat. Peringkat pertama yang dijalankan adalah untuk menilai kuasa yang dihasilkan dari RAT tunggal-pemutar. Tiga RAT diperlukan untuk memenuhi output kuasa APU, dan lokasi terbaik untuk penempatan RAT berada di bawah sayap dan perut pesawat. Peringkat kedua pula bertujuan untuk menilai jumlah kuasa yang dihasilkan oleh CRRAT dan pilihan jarak paksi optimum CRRAT. Keputusan menunjukkan bahawa jarak paksi optimum adalah 0.087 diameter pemutar, dan kecekapannya meningkat kepada 81.63% berbanding dengan RAT tunggal-rotor (RAT konvensional). Output kuasa CRRAT yang diletakkan pada jarak paksi optimum telah diakses. Kuasa yang dihasilkan oleh CRRAT adalah positif, sama dengan persetujuan keputusan simulasi. Oleh itu, CRRAT boleh digunakan untuk semua pesawat yang dilengkapi dengan RAT tradisional.

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LIST OF SYMBOLS AND ABBERIVATION

V	Air Velocity m/s
Re	Reynolds number
T	Air temperature k
L	Lift force
D	Drag force
R	Radius
r	Local radius
P	Power
C_p	Power coefficient
C_L	Lift coefficient
C_D	Drag coefficient
T	Thrust
C_T	Thrust coefficient or local thrust coefficient
F	Tip loss correction factor
A	Area
P	Pressure
a	Axial induction factor
a'	Angular induction factor
Q	Torque
u	Velocity in direction of air flow
U	Characteristic velocity, mean air flow velocity
U_∞	Free stream air flow velocity
W	Watt

°	Degree
CFD	Computational fluid dynamic
rpm	Rotations per minute
B	Number of blades
BEM	Blade element momentum
C	Airfoil chord length
ρ	Air density
ϕ	Twist angle
θ	Blade angle
α	Angle of attack
λ	Tip speed ratio
λ_r	Local tip speed ratio
λ_{opt}	Optimum tip speed ratio
μ	Coefficient of viscosity
σ	Rotor solidity
σ'	Local rotor solidity
ω	Angular velocity of the wind
Ω	Rotational speeds

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In this day and age, worldwide awareness of global warming has become significant with efforts to replace conventional fossil energy with renewable energy. Fuel combustion related to transportation has resulted in the emission of pollutants that cause damage to human health, agriculture, and sensitive ecosystems, as well as contribute to the global climate change [1]. Pollutants can be reduced by decreasing transportation emissions through devices that harvest energy, such as ram air turbine (RAT). RAT is a small wind turbine that converts mechanical energy from wind into electrical energy to operate aircraft devices. RAT has enabled the utilization of green energy in aircraft. One of the greatest contributions to the engineering world would be the production of an aircraft device that does not rely on polluting resources, such as auxiliary power unit (APU), which consumes fossil energy and is partly responsible for increasing aircraft emissions [2]. Considerable work on solar energy has been made in the aircraft industry, but research on wind energy is limited. An alternative system to power an aircraft with air-driven energy is challenging for aircraft designers [3]. To assist in such an endeavor, aircraft landing operations can be studied because set such a technology is impractical for takeoff and normal flight operations. This approach focused on improving the performance of RAT during the emergency phase and wind energy harvesting during aircraft landing for wind-powered aircraft operations in the future.

This project (i) increased the number of RATs used in aircraft, (ii) determined the best location for the placement of RATs, and (iii) applied a counter-rotating concept. The counter-rotating system is traditionally known as a highly efficient system. In this method, the generated power was higher than that from a conventional RAT. This research aimed to enhance power output in the emergency phase to maintain aircraft flight until it reached the nearest runway for landing. The energy obtained was stored in the aircraft. This system was implemented during the landing phase because aircraft decelerate while landing. Subsequently, the drag produced by RAT extraction was not restricted but used for charging batteries instead of being lost. The target of this stored energy is to dispense APU as a green energy source.

1.2 Problem Statement

An emergency phase is a crucial phase in ensuring the safety of passengers and aircraft. This phase requires additional energy without the risks of fuel leakage, which may cause fire. In some other cases, such as lack of fuel, an aircraft cannot depend on other fuel alternatives, for auxiliary power unit (APUs). Power sources such as APU have several drawbacks that make them unreliable power alternatives for aircraft. RATs are reliable sources that need to be improved to produce more energy to fulfill the required power in emergency phase.

APUs are not normally used during all flight; they are mainly utilized on the ground before the main engine of the aircraft is started [4, 5]. Disturbances, such as noise, are common attributes of APUs and are inconsistent with the surrounding objects in airports and even inside the aircraft. APUs are fuel-based engines that emit CO_2 and are therefore critical to the integrity of the environment. Furthermore, fuel cost is a challenging factor from the perspective of airline professionals. The most significant drawback of APUs is their poor efficiency, which can be as low as 8 % and 14 % in some aircraft [6, 7]. Moreover, according to some studies [8], APUs are unadoptable and should be terminated to overcome their drawbacks.

The existing RAT is a device installed in aircraft, producing energy for emergency events such as all engines failure hence large backup of power is required for longer endurance flight which helps in safe landing [4]. RATs are idle under normal circumstances and are used only during emergency phases, whereas other power systems, such as APUs, are used to power certain amenities in the aircraft, such as air conditioners and lights before engine is started [9].

RATs are not sufficiently durable for flights at high altitudes, and more energy than that supplied by RATs may be required to maintain aircraft operations during emergency phases until the nearest runway is reached for landing [10]. Counter rotating ram air turbine (CRRAT) is predicted to produce more energy than the normal RAT, thereby becoming the more effective option during emergencies that can be employed in place of the APU under normal circumstances.

1.3 Objectives of the Research

This study embarks on the following objectives:

(i) To study aerodynamic characteristic of an aircraft equipped with RAT.

(ii) To enhance the conventional RAT performance by applying counter rotating concept.

(iii) To determine the best airfoil to be used in development of the RAT model.

(iv) To investigate the performance of RAT and counter rotating ram air turbine (CRRAT) during landing phase of an aircraft.

1.4 Scope of the Study

The scope of present project focuses mainly:

(i) Conduct the testing to validate the trial CFD simulation result.

(ii) Develop and simulate six airfoils models by using SolidWorks and ANSYS-FLUENT software.

(iii) Design RAT blades by using Blade Element Momentum (BEM) theory.

(iv) Develop RAT and CRRAT model’s configurations by using SolidWorks software.

(v) Evaluate the aerodynamic performance of the RAT and CRRAT by CFD simulation using ANSYS-FLUENT software at sea level and at high altitude.

(vi) Conduct structural analysis for RAT rotor blades using ANSYS- STATIC STRUCTURAL software.

(vii) Fabricate small scale RAT and CRRAT system.

(viii) Conduct the on-site testing to validate simulation results.

(ix) Evaluate the best position for RAT on aircraft body by using CFD software.

1.5 Contribution of Research

During emergency situations, a traditional RAT is used within civil and commercial aircrafts. Presently, aircraft still employ RATs as energy resources during engine faults or any other emergency. Unlike the available research in the literature, this project aimed to improve the efficacy of RAT using a counter-rotating system (counter-rotating RAT, CRRAT). The overall performance of the RAT system was expected to improve to produce a large amount of energy in comparison with the existing traditional RAT.

1.6 Overview of the Thesis

Chapter 1: This chapter provides comprehensive information on wind turbine system and its characteristics. In this chapter, the fundamentals of wind turbine and its characteristics, aerodynamics theories, objectives of the research work, scopes of research, problem statement, contribution of research, and overview of chapters are presented.

Chapter 2: This chapter deals with a detailed review of literature related to the wind turbine system.

The literature review is classified into

(i) Conventional ram air turbine in all aircrafts.

(ii) Auxiliary power unit.

(iii) Counter rotating wind turbine specifications.

Chapter 3: Design of the rotor blade shape and optimization of power coefficient by using blade element momentum theory, computational fluid dynamic approach and computational fluid dynamic setup for airfoil, case study and ram air turbine.

Chapter 4: Presentation and discussion of results from the aerodynamic characteristics of CFD modeling (FLUENT-software) for six airfoils and selection of the best airfoil are presented and discussed. Results of the experimental data obtained during highway test of conversion wind turbine system (automobile fan) are also presented and discussed in order to validate with numerical results obtained from CFD FLUENT-software.

Chapter 5: Presentations of configuration modeling of Airbus A-380 aircraft and comparison with real aircraft configuration. Results of three dimensional CFD modeling of A-380 with ram air turbine and without ram air turbine and select the optimum position for the third ram air turbine are presented and discussed.

Chapter 6: Results of three dimensional CFD modeling of single rotor ram air turbine at sea level and at high altitude (at starting landing phase) are presented and discussed. This chapter also presents the optimum axial distance of counter rotating ram air turbine and compared with single rotor ram air turbine.

Chapter 7: The conclusions of the work are presented in this chapter and the suggestions for further study on this work are also highlighted in this chapter.

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